U.S. PATENT APPLICATION

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Invention: INTERNAL CORE PROFILE FOR THE AIRFOIL OF A TURBINE BUCKET

SPECIFICATION

INTERNAL CORE PROFILE FOR THE AIRFOIL OF A TURBINE BUCKET

BACKGROUND OF THE INVENTION

[0001]   The present invention relates to a bucket of a stage of a gas turbine and particularly relates to a first stage turbine bucket airfoil internal core profile.

[0002]   Many system requirements must be met for each stage of the hot gas path section of a gas turbine in order to meet design goals including overall improved efficiency and airfoil loading.   Particularly, the buckets of the first stage of the turbine section must meet the operating requirements for that particular stage and also meet requirements for bucket cooling flow, weight and bucket life.   Internal cooling requirements must be optimized, necessitating a unique internal core airfoil profile to meet stage performance requirements enabling the turbine to operate in a safe, efficient and smooth manner.

BRIEF DESCRIPTION OF THE INVENTION

[0003]   In accordance with the preferred embodiment of the present invention there is provided a unique internal core profile for a bucket airfoil of a gas turbine, preferably the first stage airfoil, that enhances the performance of the gas turbine.   It will be appreciated that the external airfoil shape of the bucket airfoil improves the interaction between various stages of the turbine, and affords improved aerodynamic efficiency and improved first stage airfoil aerodynamic and mechanical loading.   The external airfoil profile for the preferred

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bucket is set forth in a companion application Serial No. 10/446,688, filed May 29, 2003, titled "Airfoil Shape for a Turbine Bucket," the disclosure of which is incorporated by reference. Concomitantly, the internal core shape of the airfoil is also significant for structural reasons as well as to optimize internal cooling with appropriate wall thickness. The airfoil internal core profile is defined by a unique loci of points which achieves the necessary structural and cooling requirements whereby improved turbine performance is obtained. This unique loci of points define the internal nominal core profile and are identified by the X, Y and Z Cartesian coordinates of Table I which follows. The 1100 points for the coordinate values shown in Table I are for a cold, i.e., room temperature bucket airfoil at various cross-sections of the airfoil along its length. The positive X, Y and Z directions are axial toward the exhaust end of the turbine, tangential in the direction of engine rotation looking aft and radially outwardly toward the bucket tip, respectively. The X and Y coordinates are given in distance dimensions, e.g., units of inches, and are joined smoothly at each Z location to form a smooth continuous internal core profile section. The Z coordinates are given in non-dimensionalized form from Z=0.043 to Z=0.997. By multiplying the airfoil height dimension, e.g., in inches, by the non-dimensional Z value of Table I, the internal core profile, of the airfoil is obtained. Each defined internal core profile section in the X, Y plane is joined smoothly with adjacent profile sections in the Z direction to form the complete internal airfoil core profile.

[0004]   The preferred first stage turbine bucket airfoil includes external convex and concave, side wall surfaces with ribs extending internally between and formed integrally with the side walls defining the external side wall surfaces.   The ribs are spaced from one another between leading and trailing edges of the airfoil and define with internal wall surfaces of the airfoil side walls internal cooling passages, preferably serpentine in configuration, along the length of the airfoil.   The smooth continuing arcs extending between the X, Y coordinates to define each profile section at each distance Z extend along the internal wall surfaces of the cooling passages and between adjacent passages along each of the side walls to substantially conform to the adjacent external wall surfaces.   Consequently, each internal core profile section has envelope portions which pass through the juncture or interface between the ribs and each of the side walls as well as along the side walls of the cooling passages between the ribs.   These internal core profile sections are generally airfoil in shape and generally conform to the external airfoil shape of the bucket airfoil less the wall thickness at each Z distance.

[0005]   It will be appreciated that as each airfoil heats up in use, the internal core profile will change as a result of mechanical loading and temperature.   Thus, the cold or room temperature profile is given by the X, Y and Z coordinates for manufacturing purposes.   Because a manufactured internal bucket core profile may be different from the nominal profile given by the following table, a distance of plus or minus 0.050 inches from the

nominal profile in a direction normal to any surface location along the nominal profile defines a profile envelope for this internal airfoil core profile. The profile is robust to this variation without impairment of the mechanical, cooling and aerodynamic functions of the bucket.

[0006]   It will also be appreciated that the airfoil can be scaled up or scaled down geometrically for introduction into similar turbine designs. Consequently, the X and Y coordinates in inches and the non-dimensional Z coordinates, when converted to inches, of the internal nominal core profile given below may be a function of the same constant or number. That is, the X, Y and Z coordinate values in inches may be multiplied or divided by the same constant or number to provide a scaled up or scaled down version of the internal airfoil core profile while retaining the core profile section shape.

[0007]   In a preferred embodiment according to the present invention, there is provided a turbine bucket including an airfoil, platform, shank and dovetail, the airfoil having an internal nominal core profile substantially in accordance with Cartesian coordinate values of X, Y and Z set forth in Table I wherein the Z values are non-dimensional values convertible to Z distances in inches by multiplying the Z values by a height of the airfoil in inches, and wherein X and Y are distances in inches which, when connected by smooth continuing arcs, define internal core profile sections at each distance Z along the airfoil, the profile sections at the Z distances being joined smoothly with one another to form the airfoil internal core profile.

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[0008]   In a further preferred embodiment according to the present invention, there is provided a turbine bucket including an airfoil, platform, shank and dovetail, the airfoil having an internal nominal core profile substantially in accordance with Cartesian coordinate values of X, Y and Z set forth in Table I wherein the Z values are non-dimensional values convertible to Z distances in inches by multiplying the Z values by a height of the airfoil in inches, and wherein X and Y are distances in inches which, when connected by smooth continuing arcs, define internal core profile sections at each Z distance along the airfoil, the profile sections at the Z distances being joined smoothly with one another to form the bucket airfoil internal core profile, the X, Y and Z distances being scalable as a function of the same constant or number to provide a scaled-up or scaled-down internal core profile.

[0009]   In a further preferred embodiment according to the present invention, there is provided a turbine comprising a turbine wheel having a plurality of buckets, each of the buckets including an airfoil, a platform, a shank and a dovetail, each airfoil having an internal nominal core profile substantially in accordance with Cartesian coordinate values of X, Y and Z set forth in Table I wherein the Z values are non-dimensional values convertible to Z distances in inches by multiplying the Z values by a height of the airfoil in inches, and wherein X and Y are distances in inches which, when connected by smooth continuing arcs, define internal core profile sections at each distance Z along the airfoil, the profile sections at the Z distances being joined smoothly

with one another to form the bucket internal core profile.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010]   FIGURE 1 is a schematic representation of a hot gas path through multiple stages of a gas turbine and illustrates a first stage bucket airfoil according to a preferred embodiment of the present invention;

[0011]   FIGURE 2 is a perspective view of a bucket according to a preferred embodiment of the present invention with the bucket illustrated in conjunction with its airfoil, platform and its substantially or near axial entry dovetail connection;

[0012]   FIGURE 3 is a side elevational view of the bucket of Figure 2 and associated airfoil, platform and dovetail connection as viewed from a generally circumferential direction;

[0013]   FIGURE 4 is a top view of the bucket;

[0014]   FIGURE 5 is an end view of the bucket as viewed looking in an upstream direction; and

[0015]   FIGURE 6 is an enlarged generalized cross-sectional view taken along a cut through the bucket airfoil to illustrate an internal core profile hereof.

DETAILED DESCRIPTION OF THE INVENTION

[0016]   Referring now to the drawings, particularly to Figure 1, there is illustrated a hot gas path, generally

designated 10, of a gas turbine 12 including a plurality of turbine stages. Three stages are illustrated. For example, the first stage comprises a plurality of circumferentially spaced nozzles 14 and buckets 16. The nozzles are circumferentially spaced one from the other and fixed about the axis of the rotor. The first stage buckets 16, of course, are mounted on the turbine rotor 17. A second stage of the turbine 12 is also illustrated, including a plurality of circumferentially spaced nozzles 18 and a plurality of circumferentially spaced buckets 20 mounted on the rotor 17. The third stage is also illustrated including a plurality of circumferentially spaced nozzles 22 and buckets 24 mounted on rotor 17. It will be appreciated that the nozzles and buckets lie in the hot gas path 10 of the turbine, the direction of flow of the hot gas through the hot gas path 10 being indicated by the arrow 26.

[0017] Referring to Figure 2, it will be appreciated that the buckets, for example, the buckets 16 of the first stage are mounted on a rotor wheel, not shown, forming part of rotor 17 and include platforms 30, shanks 32 and dovetails 34. Each bucket 16 is provided with a substantially or near axial entry dovetail 34, e.g., about 15 degrees off-axis, for connection with a complementary-shaped mating dovetail, not shown, on the rotor wheel. An axial entry dovetail, however, may be provided. It will also be appreciated that each bucket 16 has an external bucket airfoil 38 as illustrated in Figures 2 and 6. Thus, each of the buckets 16 has a bucket airfoil profile at any cross-section from the airfoil platform 30 to the bucket tip 33 in the shape of an airfoil 38. In this preferred embodiment of a first

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stage turbine bucket, there are ninety-two (92) bucket airfoils. While not forming part of the present invention, each first stage bucket 16 includes a plurality of internal, generally serpentine-shaped, cooling passages 35 (Figure 6) forming several air cooling circuits extending from the platform to the tip of the bucket airfoil. These air cooling circuits exhaust cooling air from the airfoil 38 into the hot gas path at exit locations adjacent the leading and trailing edges of the airfoil.

[0018]   More particularly, each bucket airfoil 38 includes convex and concave external wall surfaces, i.e., pressure and suction surfaces 42 and 44, respectively, (Figure 6) which, with an internal core profile 40, define an airfoil wall thickness "t." Each bucket 16 also includes a plurality of ribs 46 extending between or projecting from opposite side walls 48 of the bucket. Ribs 46 are spaced from one another between leading and trailing edges 52 and 54 of the bucket airfoil, respectively, and extend generally from the platform 30 to the bucket airfoil tip 33 to define, with internal wall surface portions 49 of bucket side walls 48, the plurality of internal generally serpentine-shaped cooling passages 35. Certain of the ribs 46 terminate short of the tip of the airfoil.

[0019]   To define the internal core shape of each first stage bucket from the platform 30 to the tip 33 of the bucket airfoil 38, there is provided a unique set or loci of points in space that meet the stage requirements, bucket cooling area and wall thickness and can be manufactured. This unique loci of points, which defines

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the internal bucket core profile 40, comprises a set of 1100 points relative to the axis of rotation of the turbine. A Cartesian coordinate system of X, Y and Z values given in Table 1 below defines this internal core profile 40 of the airfoil 38 at various locations along its length. The coordinate values for the X and Y coordinates are set forth in inches in Table I although other units of dimensions may be used when the values are appropriately converted. The Z values are set forth in Table I in non-dimensional form from Z=0.043 to Z=0.997. To convert the Z value to a Z coordinate value, e.g., in inches, the non-dimensional Z value given in the table is multiplied by the height of airfoil 38 in inches. For this preferred first-stage bucket, the airfoil height from the platform 30 to the tip of the airfoil is 6.3 inches. The Z=0 non-dimensional coordinate for the preferred airfoil is 28.0 inches from the rotor centerline (engine axis). The Z=1 non-dimensional coordinate for the preferred airfoil is Z=32.3 inches from the rotor centerline (engine axis). The Cartesian coordinate system has orthogonally-related X, Y and Z axes and the X axis lies parallel to the turbine rotor centerline, i.e., the rotary axis and a positive X coordinate value is axial toward the aft, i.e., exhaust end of the turbine. The positive Y coordinate value extends tangentially in the direction of rotation of the rotor, looking aft, and the positive Z coordinate value is radially outwardly toward the bucket tip.

[0020] By defining X and Y coordinate values at selected locations in a Z direction normal to the X, Y plane, the internal core profile 40 of the bucket, e.g., representatively illustrated by the dashed and full lines

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in Figure 6, at each Z distance along the length of the airfoil can be ascertained. By connecting the X and Y values with smooth continuing arcs, each internal core profile section thus formed at each distance Z is fixed. The internal core profiles of the various internal locations between the distances Z are determined by smoothly connecting the adjacent profile sections to one another to form the core profile. These values represent the internal core profiles at ambient, non-operating or non-hot conditions.

[0021] The smooth continuing arcs extending between the X, Y coordinates to define each profile section at each distance Z extend along the internal wall surface portions 49 and between adjacent passages 35 along each of the side walls 48 from the platform to the bucket airfoil tip. Thus, each internal core profile 40 has envelope portions which pass through the juncture between the ribs 46 and the side walls 48 (represented by the dashed lines in Figure 6) as well as along the internal side walls of the cooling passages (represented by the full lines in Figure 6).

[0022] The Table I values are generated and shown to three decimal places for determining the internal core profile of the bucket. There are typical manufacturing tolerances as well as coatings which must be accounted for in the actual internal profile of the airfoil. Accordingly, the values for the profile given in Table I are for a nominal internal airfoil core profile. It will therefore be appreciated that ± typical manufacturing tolerances, i.e., ± values, including any coating thicknesses, are additive to the X and Y values given in

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Table I below. Accordingly, a distance of ± 0.050 inches in a direction normal to any surface location along the internal core profile defines an internal core profile envelope for this particular bucket design and turbine, i.e., a range of variation between measured points on the actual internal core profile at nominal cold or room temperature and the ideal position of those points as given in the Table below at the same temperature. The internal core profile is robust to this range of variation without impairment of mechanical and cooling functions.

[0023] The coordinate values given in Table I below provide the preferred nominal internal core profile envelope.

TABLE I

X	Y	Z	X	Y	Z	X	Y	Z
-1.335	-0.336	0.043	-0.157	0.180	0.043	-1.374	-0.107	0.139
-1.278	-0.312	0.043	-0.095	0.173	0.043	0.157	0.530	0.139
-1.224	-0.281	0.043	-0.033	0.163	0.043	-1.014	-0.053	0.139
-1.170	-0.247	0.043	0.029	0.148	0.043	-1.059	-0.095	0.139
-1.118	-0.212	0.043	0.088	0.128	0.043	0.108	0.567	0.139
-1.067	-0.175	0.043	0.147	0.105	0.043	0.202	0.488	0.139
-1.019	-0.134	0.043	0.204	0.079	0.043	-1.378	-0.226	0.139
-0.970	-0.096	0.043	0.260	0.049	0.043	-0.964	-0.018	0.139
-0.919	-0.059	0.043	0.313	0.017	0.043	-0.912	0.016	0.139
-0.867	-0.023	0.043	0.366	-0.019	0.043	-1.108	-0.132	0.139
-0.814	0.012	0.043	0.416	-0.057	0.043	-1.323	-0.247	0.139
-0.759	0.042	0.043	0.464	-0.097	0.043	-1.389	-0.166	0.139
-0.703	0.070	0.043	0.511	-0.139	0.043	-1.195	0.142	0.139
-0.646	0.098	0.043	0.556	-0.183	0.043	-1.158	0.191	0.139
-0.589	0.124	0.043	0.599	-0.229	0.043	-0.861	0.050	0.139
-0.530	0.147	0.043	0.639	-0.277	0.043	-1.160	-0.166	0.139
-0.470	0.165	0.043	0.679	-0.326	0.043	0.055	0.598	0.139
-0.408	0.177	0.043	0.717	-0.376	0.043	0.245	0.443	0.139
-0.346	0.184	0.043	0.754	-0.427	0.043	-1.265	-0.229	0.139
-0.283	0.187	0.043	0.791	-0.479	0.043	-1.120	0.239	0.139
-0.154	0.669	0.043	0.825	-0.532	0.043	-1.081	0.287	0.139
-0.216	0.681	0.043	0.855	-0.587	0.043	-1.040	0.333	0.139
-0.279	0.686	0.043	0.910	-0.602	0.043	-0.999	0.379	0.139
-0.342	0.682	0.043	0.949	-0.559	0.043	-0.958	0.425	0.139
-0.404	0.672	0.043	0.924	-0.502	0.043	-0.915	0.469	0.139
-0.465	0.659	0.043	0.894	-0.446	0.043	-0.866	0.506	0.139
-0.526	0.642	0.043	0.865	-0.390	0.043	-0.813	0.537	0.139
-0.586	0.622	0.043	0.835	-0.335	0.043	-0.760	0.568	0.139
-0.644	0.599	0.043	0.803	-0.281	0.043	-0.706	0.598	0.139

X	Y	Z	X	Y	Z	X	Y	Z
-0.702	0.573	0.043	0.770	-0.227	0.043	-0.652	0.627	0.139
-0.757	0.543	0.043	0.736	-0.174	0.043	-0.595	0.652	0.139
-0.811	0.510	0.043	0.703	-0.121	0.043	-0.537	0.671	0.139
-0.863	0.475	0.043	0.670	-0.067	0.043	-0.477	0.687	0.139
-0.913	0.437	0.043	0.636	-0.014	0.043	-0.417	0.698	0.139
-0.961	0.397	0.043	0.598	0.036	0.043	-0.356	0.706	0.139
-1.007	0.353	0.043	0.557	0.084	0.043	-0.294	0.707	0.139
-1.049	0.306	0.043	0.516	0.132	0.043	-0.233	0.703	0.139
-1.088	0.257	0.043	0.476	0.180	0.043	-0.173	0.691	0.139
-1.126	0.207	0.043	0.435	0.229	0.043	-0.282	0.230	0.139
-1.163	0.156	0.043	0.395	0.277	0.043	-0.344	0.230	0.139
-1.198	0.104	0.043	0.355	0.325	0.043	-0.405	0.223	0.139
-1.233	0.051	0.043	0.314	0.373	0.043	-0.466	0.214	0.139
-1.266	-0.002	0.043	0.272	0.421	0.043	-0.527	0.205	0.139
-1.300	-0.055	0.043	0.230	0.467	0.043	-0.582	0.179	0.139
-1.335	-0.108	0.043	0.184	0.511	0.043	-0.639	0.156	0.139
-1.374	-0.157	0.043	0.135	0.550	0.043	-0.696	0.133	0.139
-1.402	-0.212	0.043	0.081	0.582	0.043	-0.754	0.110	0.139
-1.412	-0.274	0.043	0.025	0.609	0.043	-0.809	0.083	0.139
-1.383	-0.327	0.043	-0.034	0.633	0.043	-1.212	-0.198	0.139
-0.220	0.186	0.043	-0.094	0.653	0.043	-1.265	-0.229	0.139

X	Y	Z	X	Y	Z	X	Y	Z
0.286	0.397	0.139	-1.328	-0.162	0.234	-0.190	0.258	0.234
0.521	0.113	0.139	-1.269	-0.158	0.234	-0.131	0.246	0.234
0.560	0.065	0.139	-1.216	-0.131	0.234	-0.073	0.232	0.234
0.598	0.016	0.139	-1.166	-0.098	0.234	-0.016	0.215	0.234
0.633	-0.034	0.139	-1.117	-0.064	0.234	0.040	0.194	0.234
0.666	-0.086	0.139	-1.069	-0.029	0.234	0.094	0.168	0.234
0.700	-0.138	0.139	-1.023	0.011	0.234	0.146	0.138	0.234
0.733	-0.190	0.139	-0.977	0.049	0.234	0.196	0.105	0.234
0.765	-0.242	0.139	-0.928	0.082	0.234	0.246	0.072	0.234
0.795	-0.296	0.139	-0.876	0.112	0.234	0.295	0.038	0.234
0.825	-0.349	0.139	-0.823	0.141	0.234	0.344	0.004	0.234
0.854	-0.404	0.139	-0.770	0.168	0.234	0.393	-0.032	0.234
0.883	-0.458	0.139	-0.716	0.193	0.234	0.440	-0.069	0.234
0.910	-0.513	0.139	-0.660	0.216	0.234	0.485	-0.108	0.234
0.881	-0.560	0.139	-0.604	0.236	0.234	0.526	-0.151	0.234
0.827	-0.553	0.139	-0.547	0.253	0.234	0.565	-0.197	0.234
0.795	-0.500	0.139	-0.488	0.262	0.234	0.604	-0.242	0.234
0.761	-0.449	0.139	-0.428	0.268	0.234	0.642	-0.289	0.234
0.726	-0.398	0.139	-0.368	0.272	0.234	0.678	-0.337	0.234
0.689	-0.348	0.139	-0.308	0.273	0.234	0.712	-0.385	0.234
0.652	-0.300	0.139	-0.249	0.268	0.234	0.746	-0.435	0.234
0.613	-0.252	0.139	-0.141	0.699	0.234	0.779	-0.485	0.234
0.573	-0.205	0.139	-0.198	0.715	0.234	0.818	-0.527	0.234
0.532	-0.160	0.139	-0.257	0.727	0.234	0.870	-0.502	0.234
0.488	-0.116	0.139	-0.317	0.733	0.234	0.863	-0.448	0.234
0.441	-0.076	0.139	-0.376	0.732	0.234	0.835	-0.395	0.234
0.392	-0.039	0.139	-0.436	0.726	0.234	0.806	-0.342	0.234
0.342	-0.004	0.139	-0.495	0.716	0.234	0.778	-0.290	0.234
0.291	0.031	0.139	-0.553	0.701	0.234	0.748	-0.238	0.234
0.239	0.064	0.139	-0.609	0.680	0.234	0.718	-0.186	0.234
0.187	0.097	0.139	-0.663	0.655	0.234	0.686	-0.135	0.234
0.134	0.128	0.139	-0.716	0.628	0.234	0.654	-0.085	0.234
0.078	0.154	0.139	-0.769	0.600	0.234	0.622	-0.035	0.234
0.020	0.174	0.139	-0.821	0.570	0.234	0.589	0.015	0.234
-0.040	0.190	0.139	-0.871	0.537	0.234	0.554	0.064	0.234
-0.100	0.204	0.139	-0.919	0.502	0.234	0.519	0.112	0.234
-0.160	0.216	0.139	-0.964	0.462	0.234	0.482	0.160	0.234
-0.221	0.225	0.139	-1.007	0.420	0.234	0.445	0.207	0.234
-1.347	-0.052	0.139	-1.047	0.376	0.234	0.408	0.254	0.234

X	Y	Z	X	Y	Z	X	Y	Z
-1.235	0.095	0.139	-1.086	0.330	0.234	0.370	0.300	0.234
-0.114	0.673	0.139	-1.124	0.284	0.234	0.331	0.346	0.234
-0.056	0.650	0.139	-1.162	0.238	0.234	0.292	0.391	0.234
0.000	0.625	0.139	-1.199	0.191	0.234	0.252	0.435	0.234
0.326	0.351	0.139	-1.236	0.144	0.234	0.210	0.478	0.234
0.365	0.303	0.139	-1.272	0.096	0.234	0.167	0.519	0.234
0.405	0.256	0.139	-1.306	0.047	0.234	0.121	0.558	0.234
0.444	0.208	0.139	-1.338	-0.004	0.234	0.074	0.595	0.234
0.482	0.161	0.139	-1.362	-0.059	0.234	0.023	0.627	0.234
-1.313	0.000	0.139	-1.367	-0.118	0.234	-0.030	0.655	0.234
-1.275	0.048	0.139	-1.330	-0.161	0.234	-0.084	0.679	0.234

X	Y	Z	X	Y	Z	X	Y	Z
-1.281	-0.082	0.330	0.019	0.225	0.330	-1.257	0.009	0.425
-1.222	-0.063	0.330	0.075	0.200	0.330	-1.203	0.024	0.425
-1.170	-0.030	0.330	0.129	0.170	0.330	-1.154	0.054	0.425
-1.120	0.006	0.330	0.178	0.133	0.330	-1.108	0.086	0.425
-1.070	0.043	0.330	0.227	0.094	0.330	-1.061	0.119	0.425
-1.022	0.081	0.330	0.276	0.057	0.330	-1.016	0.153	0.425
-0.972	0.117	0.330	0.325	0.020	0.330	-0.968	0.184	0.425
-0.920	0.150	0.330	0.375	-0.016	0.330	-0.920	0.213	0.425
-0.867	0.182	0.330	0.424	-0.054	0.330	-0.871	0.242	0.425
-0.814	0.213	0.330	0.472	-0.093	0.330	-0.822	0.271	0.425
-0.758	0.239	0.330	0.515	-0.137	0.330	-0.773	0.299	0.425
-0.700	0.260	0.330	0.555	-0.184	0.330	-0.691	0.713	0.425
-0.643	0.283	0.330	0.594	-0.232	0.330	-0.743	0.689	0.425
-0.584	0.302	0.330	0.632	-0.280	0.330	-0.794	0.665	0.425
-0.523	0.312	0.330	0.669	-0.330	0.330	-0.844	0.638	0.425
-0.461	0.316	0.330	0.705	-0.380	0.330	-0.888	0.603	0.425
-0.400	0.317	0.330	0.739	-0.431	0.330	-0.932	0.567	0.425
-0.338	0.316	0.330	0.772	-0.484	0.330	-0.977	0.531	0.425
-0.276	0.312	0.330	0.802	-0.538	0.330	-1.021	0.496	0.425
-0.150	0.720	0.330	0.832	-0.592	0.330	-1.065	0.460	0.425
-0.209	0.739	0.330	0.862	-0.645	0.330	-1.107	0.422	0.425
-0.269	0.753	0.330	0.914	-0.648	0.330	-1.145	0.380	0.425
-0.330	0.761	0.330	0.917	-0.595	0.330	-1.179	0.334	0.425
-0.392	0.763	0.330	0.890	-0.539	0.330	-1.212	0.288	0.425
-0.453	0.758	0.330	0.864	-0.484	0.330	-1.244	0.242	0.425
-0.514	0.746	0.330	0.837	-0.428	0.330	-1.275	0.194	0.425
-0.573	0.729	0.330	0.809	-0.373	0.330	-1.301	0.144	0.425
-0.630	0.706	0.330	0.780	-0.319	0.330	-1.318	0.090	0.425
-0.686	0.680	0.330	0.750	-0.265	0.330	-1.308	0.035	0.425
-0.741	0.652	0.330	0.719	-0.212	0.330	-1.260	0.009	0.425
-0.796	0.623	0.330	0.687	-0.158	0.330	-0.719	0.317	0.425
-0.849	0.592	0.330	0.656	-0.105	0.330	-0.664	0.331	0.425
-0.898	0.555	0.330	0.624	-0.052	0.330	-0.609	0.346	0.425
-0.944	0.514	0.330	0.589	-0.001	0.330	-0.554	0.359	0.425
-0.989	0.472	0.330	0.553	0.048	0.330	-0.498	0.370	0.425
-1.034	0.430	0.330	0.515	0.097	0.330	-0.442	0.365	0.425
-1.079	0.387	0.330	0.477	0.146	0.330	-0.385	0.361	0.425
-1.123	0.344	0.330	0.439	0.194	0.330	-0.329	0.357	0.425
-1.164	0.298	0.330	0.401	0.243	0.330	-0.272	0.353	0.425
-1.202	0.249	0.330	0.362	0.291	0.330	-0.216	0.344	0.425
-1.238	0.199	0.330	0.324	0.339	0.330	-0.145	0.737	0.425
-1.273	0.148	0.330	0.285	0.388	0.330	-0.198	0.759	0.425
-1.305	0.095	0.330	0.247	0.436	0.330	-0.252	0.775	0.425
-1.333	0.040	0.330	0.207	0.483	0.330	-0.308	0.786	0.425
-1.347	-0.020	0.330	0.162	0.525	0.330	-0.364	0.790	0.425
-1.317	-0.071	0.330	0.115	0.566	0.330	-0.421	0.789	0.425
-0.215	0.302	0.330	0.067	0.604	0.330	-0.477	0.785	0.425
-0.155	0.288	0.330	0.016	0.639	0.330	-0.533	0.776	0.425
-0.097	0.269	0.330	-0.037	0.670	0.330	-0.588	0.759	0.425
-0.039	0.248	29.417	-0.093	0.697	0.330	-0.640	0.737	0.425

X	Y	Z	X	Y	Z	X	Y	Z
-0.162	0.327	0.425	0.755	-0.326	0.520	0.635	-0.293	0.520
-0.108	0.310	0.425	0.729	-0.278	0.520	0.667	-0.338	0.520
-0.055	0.290	0.425	-1.226	0.110	0.520	0.696	-0.384	0.520
-0.004	0.266	0.425	-1.173	0.123	0.520	0.738	-0.411	0.520
0.046	0.239	0.425	-1.125	0.149	0.520	0.777	-0.376	0.520
0.095	0.210	0.425	-1.079	0.179	0.520	0.676	-0.182	0.520
0.142	0.178	0.425	-1.034	0.210	0.520	0.648	-0.135	0.520
0.187	0.143	0.425	-0.988	0.241	0.520	0.619	-0.088	0.520
0.230	0.107	0.425	-0.941	0.268	0.520	0.591	-0.041	0.520
0.275	0.072	0.425	-0.893	0.295	0.520	0.563	0.006	0.520
0.320	0.037	0.425	-0.846	0.323	0.520	0.532	0.052	0.520
0.365	0.002	0.425	-0.798	0.349	0.520	0.500	0.096	0.520
0.409	-0.033	0.425	-0.748	0.373	0.520	0.467	0.140	0.520
0.452	-0.070	0.425	-0.957	0.604	0.520	0.434	0.184	0.520
0.492	-0.110	0.425	-1.002	0.572	0.520	0.401	0.228	0.520
0.529	-0.154	0.425	-1.045	0.538	0.520	0.368	0.272	0.520
0.565	-0.198	0.425	-1.253	0.285	0.520	0.335	0.316	0.520
0.600	-0.242	0.425	-1.275	0.235	0.520	-0.673	0.769	0.520
0.634	-0.287	0.425	-1.289	0.182	0.520	-0.724	0.747	0.520
0.667	-0.333	0.425	-1.278	0.129	0.520	-0.773	0.723	0.520
0.699	-0.380	0.425	-1.229	0.110	0.520	-0.821	0.696	0.520
0.730	-0.428	0.425	-0.696	0.388	0.520	-0.867	0.667	0.520
0.772	-0.459	0.425	-0.642	0.400	0.520	-0.912	0.636	0.520
0.813	-0.424	0.425	-0.588	0.412	0.520	-0.144	0.758	0.520
0.792	-0.372	0.425	-0.534	0.421	0.520	-0.193	0.782	0.520
0.767	-0.321	0.425	-0.480	0.424	0.520	-0.244	0.801	0.520
0.740	-0.271	0.425	-0.425	0.420	0.520	-0.298	0.813	0.520
0.712	-0.222	0.425	-0.370	0.414	0.520	-0.352	0.821	0.520
0.684	-0.173	0.425	-0.316	0.407	0.520	-0.407	0.825	0.520
0.654	-0.124	0.425	-0.262	0.396	0.520	-0.462	0.823	0.520
0.625	-0.076	0.425	-0.209	0.381	0.520	-0.516	0.817	0.520
0.594	-0.028	0.425	-0.158	0.363	0.520	-0.570	0.805	0.520
0.564	0.020	0.425	-0.107	0.343	0.520	-0.622	0.788	0.520
0.532	0.067	0.425	-0.057	0.320	0.520	0.302	0.360	0.520
0.500	0.114	0.425	-0.007	0.296	0.520	0.270	0.404	0.520
0.466	0.160	0.425	0.040	0.269	0.520	0.236	0.447	0.520
0.432	0.205	0.425	0.086	0.239	0.520	0.202	0.490	0.520
0.397	0.250	0.425	0.130	0.206	0.520	0.164	0.530	0.520
0.362	0.294	0.425	0.173	0.171	0.520	0.124	0.567	0.520
0.327	0.339	0.425	0.215	0.136	0.520	0.082	0.602	0.520
0.290	0.382	0.425	0.257	0.101	0.520	0.038	0.636	0.520
0.254	0.426	0.425	0.299	0.066	0.520	-0.006	0.668	0.520
0.216	0.468	0.425	0.341	0.031	0.520	-0.051	0.699	0.520
0.178	0.510	0.425	0.383	-0.004	0.520	-0.097	0.730	0.520
0.137	0.550	0.425	0.425	-0.041	0.520	-1.085	0.501	0.520
0.095	0.588	0.425	0.464	-0.079	0.520	-1.122	0.461	0.520
0.051	0.623	0.425	0.501	-0.120	0.520	-1.157	0.418	0.520
0.004	0.655	0.425	0.535	-0.162	0.520	-1.192	0.375	0.520
-0.044	0.685	0.425	0.569	-0.205	0.520	-1.224	0.331	0.520
-0.094	0.712	0.425	0.603	-0.249	0.520	0.702	-0.230	0.520

X	Y	Z	X	Y	Z	X	Y	Z
-1.247	0.334	0.616	0.168	0.194	0.616	-0.706	0.514	0.711
0.831	-0.522	0.616	0.211	0.156	0.616	-0.632	0.877	0.711
-1.184	0.217	0.616	0.253	0.118	0.616	-0.681	0.861	0.711
-1.129	0.231	0.616	0.296	0.081	0.616	-0.730	0.842	0.711
-1.079	0.257	0.616	0.339	0.043	0.616	-0.777	0.822	0.711
-1.029	0.286	0.616	0.381	0.005	0.616	-0.824	0.800	0.711
-0.981	0.315	0.616	0.423	-0.035	0.616	-0.871	0.779	0.711
-0.931	0.344	0.616	0.462	-0.076	0.616	-0.918	0.757	0.711
-0.881	0.372	0.616	0.500	-0.119	0.616	-0.964	0.732	0.711
-0.831	0.398	0.616	0.535	-0.164	0.616	-1.006	0.703	0.711

X	Y	Z	X	Y	Z	X	Y	Z
-0.779	0.423	0.616	0.569	-0.210	0.616	-1.046	0.669	0.711
-0.726	0.444	0.616	0.604	-0.255	0.616	-1.082	0.632	0.711
-0.801	0.756	0.616	0.637	-0.302	0.616	-1.116	0.593	0.711
-0.851	0.729	0.616	0.668	-0.349	0.616	-0.656	0.527	0.711
-0.901	0.701	0.616	0.759	-0.367	0.616	-0.605	0.537	0.711
-0.950	0.672	0.616	0.734	-0.316	0.616	-0.553	0.540	0.711
-0.997	0.639	0.616	0.707	-0.265	0.616	-0.502	0.538	0.711
-1.041	0.603	0.616	0.680	-0.215	0.616	-0.450	0.532	0.711
-1.083	0.564	0.616	0.652	-0.165	0.616	-0.399	0.522	0.711
-1.258	0.278	0.616	0.623	-0.116	0.616	-0.349	0.511	0.711
-1.242	0.226	0.616	0.594	-0.067	0.616	-0.299	0.497	0.711
-1.188	0.216	0.616	0.564	-0.018	0.616	-0.250	0.481	0.711
-0.671	0.459	0.616	0.534	0.030	0.616	-0.202	0.461	0.711
-0.615	0.470	0.616	0.503	0.078	0.616	-0.136	0.803	0.711
-0.558	0.476	0.616	0.471	0.125	0.616	-0.181	0.829	0.711
-0.501	0.478	0.616	0.438	0.173	0.616	-0.228	0.851	0.711
-0.444	0.476	0.616	0.406	0.219	0.616	-0.276	0.871	0.711
-0.645	0.827	0.616	0.372	0.266	0.616	-0.325	0.886	0.711
-0.698	0.807	0.616	0.339	0.312	0.616	-0.376	0.897	0.711
-0.750	0.783	0.616	0.305	0.358	0.616	-0.427	0.902	0.711
-0.387	0.471	0.616	0.270	0.403	0.616	-0.479	0.902	0.711
-0.331	0.460	0.616	0.235	0.448	0.616	-0.531	0.898	0.711
-0.276	0.446	0.616	0.198	0.492	0.616	-0.582	0.889	0.711
-0.222	0.427	0.616	0.160	0.535	0.616	-1.181	0.321	0.711
-0.149	0.785	0.616	0.121	0.576	0.616	-1.130	0.326	0.711
-0.200	0.810	0.616	0.081	0.617	0.616	-1.080	0.340	0.711
-0.253	0.832	0.616	0.039	0.655	0.616	-1.033	0.361	0.711
-0.307	0.848	0.616	-0.006	0.691	0.616	-0.988	0.387	0.711
-0.364	0.858	0.616	-0.052	0.725	0.616	-0.943	0.413	0.711
-0.420	0.862	0.616	-0.099	0.756	0.616	-0.898	0.438	0.711
-0.478	0.861	0.616	0.698	-0.398	0.616	-0.851	0.461	0.711
-0.534	0.854	0.616	0.726	-0.448	0.616	-0.804	0.481	0.711
-0.590	0.843	0.616	0.753	-0.498	0.616	-0.755	0.499	0.711
-0.169	0.406	0.616	0.785	-0.418	0.616	-1.148	0.553	0.711
-0.117	0.382	0.616	-1.122	0.523	0.616	-1.179	0.511	0.711
-0.066	0.356	0.616	-1.159	0.480	0.616	-1.205	0.467	0.711
-0.016	0.329	0.616	-1.194	0.434	0.616	-1.224	0.418	0.711
0.032	0.299	0.616	-1.224	0.386	0.616	-1.230	0.367	0.711
0.079	0.266	0.616	0.810	-0.469	0.616	-1.205	0.326	0.711
0.124	0.231	0.616	0.783	-0.546	0.616	-0.155	0.438	0.711

X	Y	Z	X	Y	Z	X	Y	Z
-0.110	0.414	0.711	-1.161	0.428	0.806	-0.118	0.452	0.806
-0.065	0.388	0.711	-1.111	0.429	0.806	-0.076	0.424	0.806
-0.021	0.360	0.711	-1.062	0.441	0.806	-0.035	0.395	0.806
0.022	0.332	0.711	-1.017	0.462	0.806	0.006	0.366	0.806
0.064	0.301	0.711	-0.972	0.483	0.806	0.046	0.335	0.806
0.105	0.269	0.711	-0.926	0.504	0.806	0.085	0.304	0.806
0.144	0.236	0.711	-0.879	0.521	0.806	0.124	0.272	0.806
0.415	0.194	0.711	-0.833	0.542	0.806	0.160	0.238	0.806
0.387	0.237	0.711	-0.785	0.557	0.806	0.197	0.203	0.806
0.358	0.280	0.711	-0.737	0.571	0.806	0.232	0.168	0.806
0.328	0.323	0.711	-0.689	0.585	0.806	0.268	0.133	0.806
0.298	0.365	0.711	-0.620	0.933	0.806	0.304	0.098	0.806
0.267	0.406	0.711	-0.669	0.920	0.806	0.340	0.063	0.806
0.236	0.448	0.711	-0.717	0.906	0.806	0.375	0.027	0.806
0.204	0.488	0.711	-0.764	0.890	0.806	0.410	-0.009	0.806
0.171	0.528	0.711	-0.812	0.873	0.806	0.468	0.106	0.806
0.137	0.567	0.711	-0.859	0.855	0.806	0.440	0.148	0.806
0.102	0.605	0.711	-0.905	0.836	0.806	0.413	0.190	0.806
0.066	0.642	0.711	-0.950	0.814	0.806	0.385	0.232	0.806
0.028	0.678	0.711	-0.993	0.787	0.806	0.357	0.274	0.806
-0.011	0.712	0.711	-1.031	0.755	0.806	0.329	0.315	0.806

X	Y	Z	X	Y	Z	X	Y	Z
-0.051	0.745	0.711	-1.066	0.719	0.806	0.301	0.357	0.806
-0.093	0.775	0.711	-1.098	0.681	0.806	0.271	0.398	0.806
0.182	0.201	0.711	-1.129	0.641	0.806	0.241	0.438	0.806
0.220	0.165	0.711	-1.158	0.600	0.806	0.211	0.477	0.806
0.257	0.130	0.711	-1.182	0.556	0.806	0.180	0.517	0.806
0.295	0.094	0.711	-1.200	0.509	0.806	0.149	0.556	0.806
0.332	0.058	0.711	-1.200	0.460	0.806	0.116	0.594	0.806
0.369	0.022	0.711	-1.164	0.429	0.806	0.082	0.631	0.806
0.406	-0.015	0.711	-0.640	0.594	0.806	0.047	0.667	0.806
0.442	-0.052	0.711	-0.590	0.598	0.806	0.011	0.702	0.806
0.476	-0.091	0.711	-0.540	0.598	0.806	-0.026	0.736	0.806
0.508	-0.132	0.711	-0.490	0.595	0.806	-0.064	0.769	0.806
0.539	-0.173	0.711	-0.440	0.588	0.806	-0.103	0.800	0.806
0.570	-0.215	0.711	-0.391	0.576	0.806	0.444	-0.046	0.806
0.601	-0.256	0.711	-0.344	0.560	0.806	0.475	-0.085	0.806
0.629	-0.299	0.711	-0.298	0.540	0.806	0.506	-0.125	0.806
0.659	-0.342	0.711	-0.252	0.519	0.806	0.536	-0.165	0.806
0.705	-0.342	0.711	-0.206	0.499	0.806	0.565	-0.206	0.806
0.708	-0.294	0.711	-0.144	0.830	0.806	0.594	-0.247	0.806
0.683	-0.249	0.711	-0.186	0.856	0.806	0.623	-0.288	0.806
0.659	-0.203	0.711	-0.231	0.879	0.806	0.668	-0.285	0.806
0.634	-0.158	0.711	-0.277	0.899	0.806	0.669	-0.241	0.806
0.609	-0.112	0.711	-0.325	0.915	0.806	0.645	-0.197	0.806
0.583	-0.068	0.711	-0.373	0.929	0.806	0.621	-0.153	0.806
0.555	-0.024	0.711	-0.422	0.940	0.806	0.597	-0.109	0.806
0.528	0.020	0.711	-0.471	0.947	0.806	0.572	-0.065	0.806
0.500	0.064	0.711	-0.521	0.948	0.806	0.546	-0.022	0.806
0.472	0.107	0.711	-0.571	0.943	0.806	0.520	0.021	0.806
0.443	0.151	0.711	-0.161	0.477	0.806	0.494	0.064	0.806

X	Y	Z	X	Y	Z	X	Y	Z
-1.136	0.536	0.902	0.038	0.360	0.902	-0.585	1.069	0.997
-1.083	0.533	0.902	0.078	0.326	0.902	-0.631	1.070	0.997
-1.032	0.544	0.902	0.117	0.291	0.902	-0.677	1.068	0.997
-0.982	0.562	0.902	0.155	0.255	0.902	-0.723	1.061	0.997
-0.933	0.580	0.902	0.192	0.218	0.902	-0.768	1.051	0.997
-0.883	0.596	0.902	0.229	0.181	0.902	-0.812	1.038	0.997
-0.832	0.609	0.902	0.266	0.143	0.902	-0.855	1.021	0.997
-0.781	0.621	0.902	0.302	0.105	0.902	-0.896	1.001	0.997
-0.729	0.630	0.902	0.339	0.067	0.902	-0.936	0.979	0.997
-0.677	0.639	0.902	0.375	0.029	0.902	-0.975	0.953	0.997
-0.632	0.993	0.902	0.410	-0.010	0.902	-1.011	0.925	0.997
-0.684	0.983	0.902	0.444	-0.050	0.902	-1.046	0.895	0.997
-0.735	0.969	0.902	0.476	-0.092	0.902	-1.079	0.863	0.997
-0.784	0.953	0.902	0.507	-0.134	0.902	-1.109	0.828	0.997
-0.834	0.935	0.902	0.539	-0.176	0.902	-1.136	0.791	0.997
-0.883	0.917	0.902	0.569	-0.219	0.902	-1.158	0.751	0.997
-0.932	0.896	0.902	0.634	-0.207	0.902	-1.173	0.707	0.997
-0.977	0.871	0.902	0.609	-0.161	0.902	-1.171	0.662	0.997
-1.017	0.837	0.902	0.584	-0.115	0.902	-1.140	0.629	0.997
-1.053	0.798	0.902	0.558	-0.069	0.902	-1.096	0.616	0.997
-1.086	0.758	0.902	0.533	-0.023	0.902	-1.050	0.615	0.997
-1.118	0.715	0.902	0.506	0.023	0.902	-1.004	0.620	0.997
-1.147	0.672	0.902	0.479	0.068	0.902	-0.959	0.630	0.997
-1.170	0.625	0.902	0.451	0.112	0.902	-0.914	0.642	0.997
-1.175	0.573	0.902	0.423	0.156	0.902	-0.870	0.654	0.997
-1.140	0.537	0.902	0.394	0.200	0.902	-0.825	0.664	0.997
-0.625	0.641	0.902	0.365	0.244	0.902	-0.780	0.673	0.997
-0.573	0.640	0.902	0.336	0.288	0.902	-0.734	0.678	0.997
-0.520	0.636	0.902	0.307	0.332	0.902	-0.688	0.681	0.997
-0.468	0.629	0.902	0.278	0.376	0.902	-0.131	0.863	0.997
-0.417	0.617	0.902	0.249	0.419	0.902	-0.167	0.891	0.997
-0.367	0.600	0.902	0.219	0.462	0.902	-0.204	0.918	0.997

X	Y	Z	X	Y	Z	X	Y	Z
-0.318	0.581	0.902	0.187	0.505	0.902	-0.242	0.944	0.997
-0.270	0.560	0.902	0.154	0.545	0.902	-0.282	0.968	0.997
-0.223	0.537	0.902	0.120	0.585	0.902	-0.322	0.990	0.997
-0.177	0.512	0.902	0.084	0.624	0.902	-0.364	1.011	0.997
-0.142	0.843	0.902	0.049	0.662	0.902	-0.406	1.028	0.997
-0.186	0.872	0.902	0.012	0.700	0.902	-0.450	1.043	0.997
-0.231	0.900	0.902	-0.025	0.738	0.902	-0.494	1.056	0.997
-0.277	0.925	0.902	-0.062	0.774	0.902	-0.539	1.064	0.997
-0.324	0.948	0.902	-0.101	0.810	0.902	-0.642	0.681	0.997
-0.373	0.967	0.902	0.598	-0.263	0.902	-0.596	0.678	0.997
-0.423	0.981	0.902	0.624	-0.308	0.902	-0.550	0.672	0.997
-0.475	0.991	0.902	0.650	-0.354	0.902	-0.505	0.663	0.997
-0.527	0.996	0.902	0.675	-0.400	0.902	-0.460	0.652	0.997
-0.580	0.997	0.902	0.710	-0.433	0.902	-0.416	0.639	0.997
-0.132	0.485	0.902	0.730	-0.394	0.902	-0.373	0.624	0.997
-0.088	0.456	0.902	0.706	-0.347	0.902	-0.330	0.606	0.997
-0.045	0.425	0.902	0.682	-0.300	0.902	-0.288	0.587	0.997
-0.003	0.393	0.902	0.659	-0.253	0.902	-0.248	0.565	32.287

X	Y	Z
-0.208	0.542	0.997
0.213	0.186	0.997
0.243	0.152	0.997
0.274	0.117	0.997
0.304	0.082	0.997
0.333	0.046	0.997
0.362	0.010	0.997
0.390	-0.026	0.997
0.418	-0.062	0.997
0.446	-0.099	0.997
0.477	-0.133	0.997
0.522	-0.135	0.997
0.553	-0.103	0.997
0.550	-0.059	0.997
0.527	-0.018	0.997
0.504	0.021	0.997
0.482	0.062	0.997
0.459	0.102	0.997
0.436	0.142	0.997
0.412	0.181	0.997
0.388	0.220	0.997
0.364	0.260	0.997
0.339	0.298	0.997
0.314	0.337	0.997
0.289	0.376	0.997
0.263	0.414	0.997
0.236	0.452	0.997
0.210	0.489	0.997
0.182	0.526	0.997
0.154	0.563	0.997
0.126	0.599	0.997
0.096	0.634	0.997
0.066	0.669	0.997
0.036	0.704	0.997
0.004	0.737	0.997
-0.028	0.770	0.997
-0.062	0.802	0.997
-0.096	0.833	0.997
-0.168	0.518	0.997
-0.130	0.493	0.997
-0.093	0.466	0.997
-0.056	0.438	0.997
-0.020	0.409	0.997

X	Y	Z
0.015	0.379	0.997
0.050	0.349	0.997
0.084	0.318	0.997
0.117	0.286	0.997
0.149	0.253	0.997
0.181	0.220	0.997
0.213	0.186	0.997

[0024]   It will also be appreciated that the internal core profile of the airfoil disclosed in the above Table may be scaled up or down geometrically for use in other similar turbine designs.   Consequently, the coordinate values set forth in Table 1 may be scaled upwardly or downwardly such that the internal profile shape of the airfoil remains unchanged.   A scaled version of the coordinates in Table 1 would be represented by X, Y and Z coordinate values of Table 1, with the non-dimensional Z coordinate value converted to inches, multiplied or divided by a constant number.

[0025]   While the invention has been described in connection with what is presently considered to be the most practical and preferred embodiment, it is to be understood that the invention is not to be limited to the disclosed embodiment, but on the contrary, is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims.